

# AN IMPROVED ALGORITHM FOR RETRIEVAL OF SNOW WETNESS USING C-BAND AIRSAR

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## INTRODUCTION

Backscattering measurements by SAR from wet snow covered terrain are affected by two sets of parameters: (1) sensor parameters which include the frequency, polarization, and viewing geometry, and (2) snowpack parameters which include snow density, liquid water content, particle sizes and shapes of ice and water, type of the correlation function and its parameters of surface roughness.

The identified scattering mechanics of wet snow-covered terrain from the model predictions and measurements of the polarimetric properties (Shi et al, 1992) shows that the first-order surface and volume scatterings are dominated scattering source. We can construct, in general, the backscatter model of wet snow-covered terrain with two components:

$$\sigma_t^{pp} = \sigma_v^{pp} + \sigma_s^{pp} \quad (1)$$

where  $\sigma$  is the backscattering coefficient.  $pp$  indicates polarization. The subscript  $t$ ,  $s$ , and  $v$  represent the total backscattering, the surface backscattering from the air-snow interface, and the volume backscattering from the snowpack, respectively. The relation between backscattering and snow wetness is controlled by the scattering mechanism. When the surface is smooth, volume scattering is the dominant scattering source. As snow wetness increases, both the volume scattering albedo and the transmission coefficients greatly decrease. This results in a negative correlation between the backscattering signals and snow wetness. When the surface is not smooth, increasing snow wetness results in greatly increased surface scattering interaction and surface scattering becomes the dominant scattering process. Therefore, a positive correlation between the backscattering signals and snow wetness will be observed. The characteristics of above relationships makes it difficult to derive an empirical relation from field measurements and a physical based algorithm is needed for a large region snow wetness estimation.

Our previous works (Shi et al., 1993) indicated that the ratios of  $\sigma^{vv}$  to  $\sigma^{hh}$  and  $\sigma^{vvhh}$  to  $\sigma^{hh}$  could be used for snow wetness retrieval at C-band. The development of the inversion model was based upon the relations of the first-order surface and volume backscattering model predictions. The small perturbation model was used to predict the relations between snow wetness and above ratios, which are independent of surface roughness and only dependent on the local incidence angle and snow dielectric property. Our resent study (Shi et al., 1993) showed an over-estimating snow wetness by this method. The tested results had an average relative error about 23 percent and the maximum error could reach 50 percent. This is because the small perturbation model can only be applied to smooth surface. The accuracy of this model is generally within 2 dB for surfaces with standard deviation of surface height less than 0.1 of the wavelength and small surface correlation length (kl less than 3) (Chen et al., 1988).

Due to the surface roughness parameters of most of natural surface are outside the range of the valid conditions for the Small Perturbation and Geometric Optical models, application of these surface scattering models are greatly limited to certain types of the surface roughness conditions. The recently developed Integral Equation Model (IEM) (Fung et al., 1991 and 1992) allows a much wider range of the surface roughness conditions. However, it does not allow to apply this model directly to infer geophysical parameters because of the complicity of this model and the limited independent observations provided by SAR measurements.

This study shows our continue efforts on developing and testing the algorithm for retrieval snow wetness using C-band JPL AIRSAR data. We show (1) a simplified surface backscattering model particularly derived for wet snow physical conditions from the numerical simulations by IEM model, and (2) snow wetness retrieval model test and comparison with ground measurements using C-band AIRSAR data,

### INVERSION MODEL DEVELOPMENT

The volume backscattering coefficient is a function of the permittivity and the volume scattering albedo (depending on snow density, wetness, particle size, size variation and shape). Under the spherical grain or random oriented particles assumption, the relationship for the first-order volume backscattering signals of VV and HH polarizations can be also obtained:

$$D_T(\theta_i, \epsilon_r) = \frac{\sigma_v^{vv}}{\sigma_h^{hh}} = \frac{\Upsilon_{vv}^2(\theta_i, \epsilon_r)}{\Upsilon_{hh}^2(\theta_i, \epsilon_r)} \quad (2)$$

where  $\Upsilon_{vv}^2$  and  $\Upsilon_{hh}^2$  are double pass of the power transmission coefficients.

The surface backscattering is a function of the permittivity of wet snow (depending on snow density and wetness) and the roughness of the air-snow interface which is described by the auto-correlation function of random surface height, the standard deviation of the surface height, and the correlation length. Due to complicity of IEM model and the limited number of independent observations from the polarimetric SAR, we need to minimize or combine these factors in order to develop an algorithm of measuring snow wetness.

Using IEM model, we simulated surface backscattering coefficients of  $\sigma_s^{vv}$  and  $\sigma_s^{vvhh}$  at C-band for the possible snow wetness and surface roughness conditions. The simulated backscattering coefficients cover the ranges for snow wetness from 1 percent to 13 percent, for the incidence angle from 25° to 70°, for the standard deviation of random surface height from 0.1 mm to 15 mm, and for the surface correlation length 0.5 cm to 25 cm. Through statistical analysis, we found a simplified form for the backscattering coefficients

$$\sigma_s^{hh} = |\alpha_{hh}|^2 \left[ \frac{1.12S_R}{(0.11 + S_R)} \right]^{1.2} \quad (3)$$

$$\sigma_s^{vvhh} = \text{Re}[\alpha_{vv}\alpha_{hh}] \left[ \frac{1.06S_R}{(0.17\sin(\theta_i) + S_R)} \right]^{1.2} \quad (4)$$

$$\sigma_s^{vv} = \frac{|\alpha_{vv}|^2 1.05S_R \cos(\theta_i)}{(0.46\sin^2(\theta_i) + 1.3S_R \cos(\theta_i))} \quad (5)$$

where  $\alpha_{vv}$  and  $\alpha_{hh}$  are same as that for the small perturbation model and given in (Tsang et al., 1985). The  $S_R$  is the surface roughness parameter, which is  $S_R = ks^2 W \cos^2(\theta)$ .  $W$  is the Fourier transform of the power spectrum of the surface correlation function.

As predicated by the models of the first-order surface and volume backscattering, the correlation coefficient in H and V channel is perfect correlated. The real part of the cross product of VV and HH complex scattering elements,  $\text{Re}[S_i^{vv} S_i^{hh*}]$ , can be related to the surface and volume backscattering coefficients by

$$\sigma_i^{vvhh} = \text{Re}[S_i^{vv} S_i^{hh*}] = \sigma_v^{vvhh} + \sigma_s^{vvhh} \quad (6)$$

The ratio of  $\sigma_v^{vvhh}/\sigma_v^{hh}$  can be written as

$$D_{TV}(\theta_i, \epsilon_r) = \frac{\sigma_v^{vvhh}}{\sigma_v^{vv}} = \frac{Re[T_{vvhh}^2]}{\Upsilon_{vv}^2} \quad (7)$$

Using Equations (1) to (7), we can derive two inversion formula for snow wetness retrieval as

$$D_{TV}\sigma_t^{vv} - \sigma_t^{vvhh} = D_{TV}\sigma_s^{vv} - \sigma_s^{vvhh} \quad (8)$$

and

$$D_T\sigma_t^{hh} - \sigma_t^{vv} = D_T\sigma_s^{hh} - \sigma_s^{vv} \quad (9)$$

In Equation (8) and (9), there are only two unknowns: the snowpack permittivity and the surface roughness parameter  $S_R$ . Therefore, we can obtain the estimations of snow wetness and surface roughness parameter by solve the equation (8) and (9) simultaneously.

### COMPARISON WITH AIRSAR MEASUREMENTS

The data used in this study for testing the algorithm are from the NASA/JPL airborne imaging polarimeter overflying the central part of the Ötztal test site on June 25, 1991. The experiment consisted of three flight passes at a flight altitude about 10,600 meter a.s.l. Two of the flight lines were aligned in E-W direction, shifted by 4 km. in latitude. Another was collected from an W-E flight line, resulting in opposite look direction.

At the time of the radar survey the snow cover was wet at all elevation zones. In ground sampled data, the liquid water content in the top snow layer (5 cm), obtained from average values at 0 and 5 cm, was ranged from 4.0 to 7.2 percent by volume. Snow grain radii were from 1.0 to 2 mm in the top snow layer. The snow densities and depths (over glacier ice) ranged from 460–530 kg m<sup>-3</sup> and from 40–205 cm respectively. In addition to snow physical parameters measurements, surface roughness was measured by a laserimeter. The standard deviations of surface height were 0.1–0.7 cm; correlation lengths ranged 1–23 cm.

To test the algorithm for measuring snow wetness over a large area, snow-covered area map was first obtained and non-snow-covered area was masked. Secondly, the stokes matrix for a given pixel was determined by the mean value within a  $3 \times 3$  window in order to reduce the effect of image speckle. Figure 1 shows two maps of the inversion-derived snow wetness, which are derived from two images with E-W flight passes. The image brightness is proportional to the snow wetness by volume. The black region is non-snow-covered area. At most of the lower elevation region, the inferred liquid water content of the top snow layer was in the order of 5 to 7 percent by volume. It decreases to 1 or 4 percent at the higher elevations. This agrees well ground regional conditions. Both snow wetness maps derived from different incident angle showed a consistent results within 2 percent. Figure 2. shows the comparisons between the field measurements and the SAR derived snow wetness for the locations where the ground measurements were available. The line indicates where the snow wetness is exactly same from the ground and SAR derived measurements. The measurements above and below this line indicate an over-estimation and under-estimation, respectively. The relative error was within 25 percent from all measurements. In overall, the algorithm performed well and provided a consistent results, less than 2 percent for absolute values, at different incidence angles. The magnitude of the error is within the range we expected. Since the algorithm performed at different incident angle produces the consistent result, it is also possible to calibrate the algorithm.

### CONCLUSIONS

This study shows recent results of our efforts to develop and verify an algorithm for snow wetness retrieval from a polarimetric SAR. Our algorithm is based on the first-order

scattering model with consideration of both surface and volume scattering. It operates at C-band and requires only rough information about the ice volume fraction in snowpack. Comparing ground measurements and inferred from JPL AIRSAR data, the results showed that the relative error inferred from SAR imagery was within 25 percent. The inferred snow wetness from different looking geometries (two flight passes) provided consistent results within 2 percent. Both regional and point measurement comparisons between the ground and SAR derived snow wetness indicates that the inversion algorithm performs well using AIRSAR data and should prove useful for routine and large-area snow wetness (in top layer of a snowpack) measurements.

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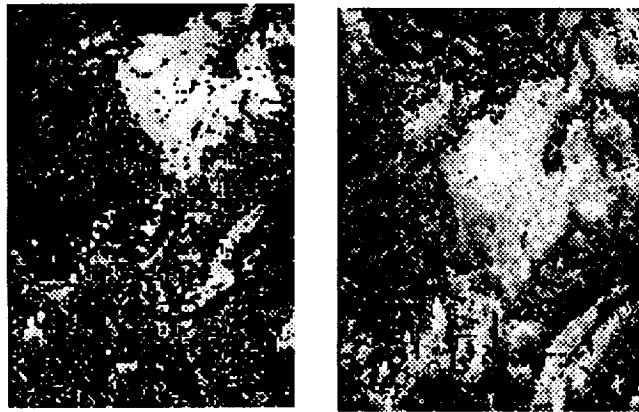


Figure 1. C-band SAR derived snow wetness maps.

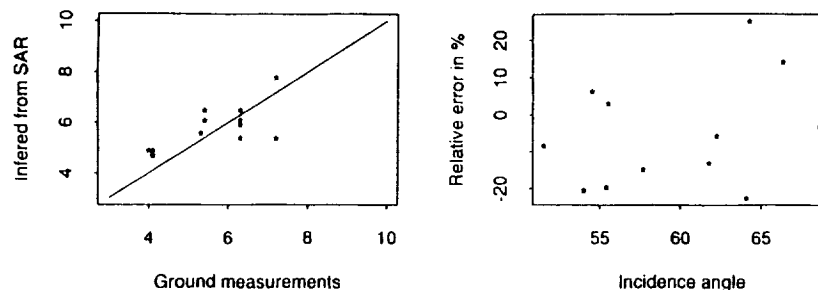


Figure 2. Comparison of ground measurements with SAR derived snow wetness.